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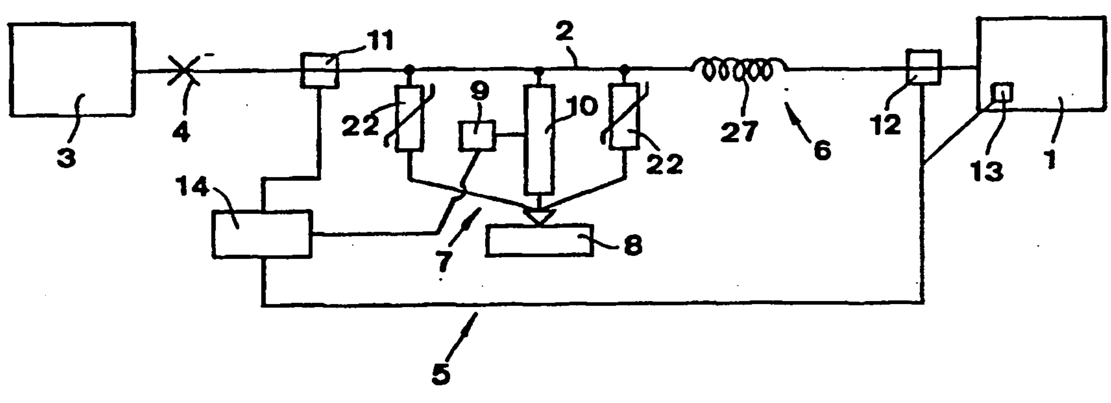

(57) Abstract

This invention is related to a device and a method for protection, in an electric power plant, of an object (1) against overcurrents from a network (3) or another equipment included in the high voltage plant, the device comprising a switching device (4) in a line (2) between the object and the network/equipment. The line (2) between the object and the network/equipment is connected to an arrangement (5) reducing overcurrents towards the object (1), said arrangement (5) being activatable for overcurrent reduction with the assistance of an arrangement (11-13) detecting overcurrent conditions within a time period substantially shorter than the breaktime of the switching device (4).

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DEVICE AND METHOD RELATING TO PROTECTION OF AN OBJECT AGAINST OVERCURRENTS COMPRISING OVERCURRENT REDUCTION AND CURRENT LIMITATION.

FILED OF THE INVENTION AND PRIOR ART

This invention is related to a device in an electric power plant for protection of an object connected to an electric power network or another equipment in the electric power plant from fault-related over-currents, the device comprising a switching device in a line between the object and the network/equipment. In addition, the invention includes a method for protecting the object from over-currents.

The electric object in question is preferably formed by an apparatus having a magnetic circuit requiring protection against fault-related over-currents, i.e. in practice short-circuit currents. As an example, the object may be a transformer or reactor. The present invention is intended to be applied in connection with medium or high voltage. According to IEC norm, medium voltage refers to 1-72,5 kV whereas high voltage is >72,5 kV. Thus, transmission, sub-transmission and distribution levels are included.

In prior power plants of this nature one has resorted to, for protection of the object in question, a conventional circuit-breaker (switching device) of such a design that it provides galvanic separation on breaking. Since this circuit breaker must be designed to be able to break very

high currents and voltages, it will obtain a comparatively bulky design with large inertia, which reflects itself in a comparatively long break-time. It is pointed out that the over-current primarily intended is the short-circuit current occurring in connection with the protected object, for instance as a consequence of faults in the electric insulation system of the protected object. Such faults means that the fault current (short-circuit current) of the external network/equipment will tend to flow through the arc created in the object. The result may be a very large breakdown. It may be mentioned that for the Swedish power network, the dimensioning short-circuit current/fault-current is 63 kA. In reality, the short-circuit current may amount to 40-50 kA.

A problem with said circuit-breaker is the long-break time thereof. The dimensioning break-time (IEC-norm) for completely accomplished breaking is 150 milliseconds (ms). It is associated to difficulties to reduce this break-time to less than 50-130 ms depending upon the actual case. The consequence thereof is that when there is a fault in the protected object, a very high current will flow through the same during the entire time required for actuating the circuit-breaker to break. During this time the full fault current of the external power network involves a considerable load on the protected object. In order to avoid damage and complete breakdown with respect to the protected object, one has, according to the prior art, constructed the object so that it manages, without appreciable damage, to be subjected to the short-circuit current/fault current during the break-time of the circuit breaker. It is pointed out that a short-circuit current (fault current) in the protected object may be composed of the own contribution of the object to the fault current and the current addition emanating from the network/equipment. The own contribution of the object to the fault current is not

influenced by the functioning of the circuit-breaker but the contribution to the fault current from the network/equipment depends upon the operation of the circuit breaker. The requirement for constructing the protected object so that it may withstand a high short-circuit current/fault current during a considerable time period means substantial disadvantages in the form of more expensive design and reduced performance.

Present day transformers and reactors rely, with respect to protection, on their own inherent transient current limiting ability, as a consequence of high inductance, in addition to the function of the conventional circuit breaker described above. Although the present invention is applicable on such conventional transformeras and reactors, it is with special advantage applicable on new inventive transformers or reactors, which will be discussed more in detail hereunder and which by their design present a lower inductance/impedance than conventional transformers and reactors and which therefore cannot constitute, to an equally high degree, an inductively current limiting unit involving an own protection against over-currents as well as a protection for electric units located before and after respectively the transformer/reactor. In such non conventional transformers and reactors, it is of course particularly important that the protection device operates rapidly to delimit the damaging effect of the fault.

In order to simplify the understanding, a conventional power transformer will be explained hereunder. What is stated is in all essentials also applicable with respect to reactors. Reactors may be designed as single-phase and three-phase reactors. As regards insulation and cooling there are, in principle, the same embodiments as for transformers. Thus, air-insulated and oil-insulated, self-cooled, pressure-oil-cooled, etc., reactors are available.

Although reactors have one winding (per phase) and may be designed both with and without an iron core, the following description is to a large extent relevant also to reactors.

A conventional power transformer comprises a transformer core, in the following referred to as a core, often of laminated oriented sheet, usually of silicone iron. The core comprises a number of core limbs, connected by jokes which together form one or more core windows. Transformers with such a core are often referred to as core transformers. Around the core limbs there are a number of windings which are normally referred to as primary, secondary and control windings. As far as power transformers are concerned, these windings are practically always concentrically arranged and distributed along the length of the core limbs. The core transformer normally has circular coils as well as a tapering core limb section in order to fill up coils as closely as possible.

Sometimes also other types of core designs occur, for example those which are included in so called shell-type transformers. These have as a rule rectangular coils and a rectangular limb section.

Conventional power transformers, in the lower part of the power range in question, namely from 1 VA to the 1000 MVA range, are sometimes designed with air-cooling to carry away the unavoidable inherent losses. For protection against contact, and possibly for reducing the external magnetic field of the transformer, it is often provided with an outer casing provided with ventilation openings.

Most of the conventional power transformers, however, are oil-cooled. One of the reasons therefore is that the oil has the additional very important function as insulating

medium. An oil-cooled and oil-insulated conventional power transformer must therefor be surrounded by en external tank on which, as will be clear from the description below, very high demands are placed.

Conventional oil-insulated power transformers are also manufactured with water-cooling of the oil.

The following part of the description will for the most part refer to conventional oil filled power transformers.

The windings mentioned above are formed from one or more series-connected coils built up of a number of series-connected turns. In addition, the coils are provied with a special device to allow switching between the terminals of the coils. Such a device may be designed for changeover with the aid of screw joints or more often with the aid of a special switch which is operable in the vicinty of the tank. In the event that switching can take place for a transformer under voltage, the changeover switch is referred to as an on-load tap changer whereas otherwise it is referred to as a de-energized tap changer.

Regarding oil-cooled and oil-insulated power transformers in the upper power range, the breaking element of the on-load tap changers are placed in spceial oil-filled containers with direct connection to the transformer tank. The breaking elements are operated purely mechanically via a motor driven rotating shaft and are arranged so as to obtain a fast movement during the switching when the contact is open and a slower movement when the contact is to be closed. The on-load tap changer as such, however, are placed in the actual transformer tank. During the operation, arcing and sparking arise. This leads to degradation of the oil in the containers. In order to obtain less arcs and hence also less formation of soot and less wear on the

contacts, the on-load tap changers are normally connected to the high-voltage side of the transformer. This is due to the fact that the currents which need to be broken and connected, respectively, are smaller on the high-voltage side than if the on-load tap changers were to be connected to the low-voltage side. Failure statistics of conventional oil-filled power transformers show that it is often the on-load tap changers which give rise to faults.

In the lower power range of oil-cooled and oil-insulated power transformers, both the on-load tap changers and their breaking element are placed inside the tank. This means that the above-mentioned problems with degradation of the oil because of arcs during operation etc. effect the whole oil system.

A considerable difference between a conventional power transformer and such a non-conventional power transformer intended with the invention refers to the conditions with respect to insulation. For that reason it will be described more in detail with reference to Fig 1 why the insulation system is built as it is in conventional power transformers.

From the point of view of applied or induced voltage, it can broadly be said that a voltage which is stationary across a winding is distributed equally onto each turn of the winding, that is the turn voltage is equal on all turns.

From the point of view of electric potential, however, the situation is completely different. One end of a winding, assuming the lower end of a winding 51 according to Fig 12, is normally connected to earth. This means, however, that the electric potential of each turn increases linearly from practically zero in the turn which is nearest

the earth potential up to a potential in the turns which are at the other end of the winding which correspond to the applied voltage.

In Fig 12, which in addition to a winding 51 comprises a core 52, a simplified and fundamental view of the equipotential lines 53 with respect to the electric field distribution is shown for a conventional winding for a case where the lower part of the winding is assumed to be at earth potential. This potential distribution determines the composition of the insulation system, since it it necessary to have sufficient insulation both between adjacent turns of the winding and between each turn and earth. Thus, the Figure shows that the upper part of the winding is subjected to the highest insulation loads. The design and location of a winding relative to the core are in this way determined substantially by electric field distribution in the core window.

The turns in an individual coil are normally brought together into a geometrical coherent unit, physically delimited from the other coils. The distance between the coils is also determined by the di-electric stress which may be allowed to occur between the coils. Thus, this means that a certain insulation distance is also required between the coils. According to the above, sufficient insulation distances are also required to the other electrically conducting objects which are within the electric field from the electric potential occurring locally in the coils.

Thus, it is clear from the above description that for the individual coils, the voltage difference internally between physically adjacent conductor elements is relatively low whereas the voltage difference externally in relation to other metal objects, including the other coils, may be relatively high. The voltage difference is determined by

the voltage induced by magnetic induction as well as by the capacitively distributed voltages which may arise from a connected external electrical system on the external connections of the transformer. The voltage types which may enter externally comprise, in addition to operating voltage, lightening over-voltages and switching over-voltages.

In the current leads of the coils, additional losses arise as a result of the magnetic leakage field around the conductor. To keep these losses as low as possible, especially for power transformers in the upper power range, the conductors are normally divided into a number of conductor element, often referred to as strands, which are parallel-connected during operation. These strands must be transposed according to such a pattern that the induced voltage in each strand becomes as identical as possible and so that the difference in induced voltage between each pair of strands becomes as small as possible for internally circulating current components to be kept down at a reasonable level from the loss point of view.

When designing transformers according to the prior art, the general aim is to have as large a quantity of conductor material as possible within a given area limited by the so called transformer window, generally described as having as high a fill factor as possible. The available space shall comprise, in addition to the conductor material, also the insulating material associated with the coils, partly internally between the coils and partly to other metallic components including the magnetic core.

The insulation system, partly within a coil/winding and partly between coils/windings and other metal parts, is normally designed as a solid cellulose- or varnish-based insulation nearest the individual conductor element, and

outside of this as solid cellulose and liquid, possibly also gaseous, insulation. Windings with insulation and possible bracing parts in this way represent large volumes which will be subjected to high electric field strengths which arise in and around the active electromagnetic parts of the transformer. To be able to predetermine the dielectric stresses which arise and achieve a good dimensioning with a minimum risk of breakdown, good knowledge of the properties of insulating materials is required. It is also important to achieve such a surrounding environment that it does not change or reduce the insulating properties.

The currently predominant insulation system for high-voltage conventional power transformers comprises cellulose material as the solid insulation and transformer oil as the liquid insulation. The transformer oil is based on so-called mineral oil.

Transformer oil has a dual function since, in addition to the insulating function, it actively contributes to cooling of the core, the winding, etc, by removal of the loss heat of the transformer. Oil cooling requires oil pump, an external cooling element, and expansion coupling etc.

The electrical connection between the external connections of the transformer and the immediately connected coils/windings is referred to as a bushing aiming at a conductive connection through the tank which, in the case of oil-filled power transformers, surround the actual transformer. The bushing is also a separate component fixed to the tank and is designed to withstand the insulation requirements being made, both on the outside and the inside of the tank, while at the same time it

should withstand the current loads occurring and the ensuing current forces.

It should be pointed out that the same requirements for the insulation system as described above regarding the windings also apply to the necessary internal connections between the coils, between bushings and coils, different types of change-over switches and the bushings as such.

All the metallic components inside a conventional power transformer are normally connected to a given ground potential with the exception of the current-carrying conductors. In this way, the risk of an unwanted, and difficult-to-control, potential increase as a result of capacity voltage distribution between current leads at high potential and ground is avoided. Such an unwanted potential increase may give rise to partial discharges, so-called corona. Corona may be revealed during the normal acceptance tests, which partially are performed, compared with rated data, increased voltage and frequency. Corona may give rise to damage during operation.

The individual coils in a transformer must have such a mechanical dimensioning that they may withstand any stresses occurring as a consequence of currents arising and the resultant current forces during a short-circuit process. Normally, the coils are designed such that the forces arising are absorbed within each individual coil, which in turn may mean that the coil can not be dimensioned optimally for its normal function during normal operation.

Within a narrow voltage and power range of oil-filled power transformers, the windings are designed as so-called sheet windings. This means that the individual conductors mentioned above are replaced by thin sheets. Sheet-wound power transformers are manufactured for voltages of up to 20-30 kV and powers of up to 20-30 MW.

The insulation system of conventional power transformers within the upper power range requires, in addition to a relatively complicated design, also special manufacturing measures to utilize the properties of the insulation system in the best way. For a good insulation to be obtained, the insulation system shall have a low moisture content, the solid part of the insulation shall be well impregnated with the surrounding oil and the risk of remaining "gas" pockets in the solid part must be minimal. To ensure this, a special drying and impregnating process is carried out on a complete core with windings before it is lowered into a tank. After this drying and impregnating process, the transformer is lowered into the tank which is then sealed. Before filling of oil, the tank with the immersed transformer must be emptied of all air. This is done in connection with a special vacuum treatment. When this has been carried out, filling of oil takes place.

To be able to obtain the promised service life, etc, of a conventional oil-filled transformer, pumping out to almost absolute vacuum is required in connection with the vacuum treatment. Thus, this presupposes that the tank which surrounds the transformer is designed for full vacuum, which entails a considerable consumption of material and manufacturing time.

If electric discharges occur in an oil-filled power transformer, or if a local considerable increase of the

temperature in any part of the transformer occurs, the oil is disintegrated and gaseous products are dissolved in the oil. The transformers are therefore normally provided with monitoring devices for detecting of gas dissolved in the oil.

For weight reasons, large power transformers are transported without oil. In situ installation of the transformer at a customer requires, in turn, renewed vacuum treatment. In addition, this is a process which has to be repeated each time the tank is opened for some action or inspection.

It is obvious that these processes are very time-consuming and cost-demanding and constitute a considerable part of the total for manufacturing and repair while at the same time requiring access to extensive resources.

The insulating material in a conventional power transformer consitutes a large part of the total volume of the transformer. For a conventional power transformer the upper power range, oil quantities in the order of magnitude of several tens of cubic meters of transformer oil are not unusual. The oil which exhibits a certain similarity to diesel oil is thinly fluid and exhibits a relatively low flash point. Thus, is is obvious that oil together with the cellulose constitutes a non-negligeable fire hazard in the case of unintentional heating, for example at an internal flashover, and a resultant oil spillage.

It is also obvious that, especially in conventional oil-filled power transformers, there is a very large transport problem. A conventional oil-filled power transformer in the upper power range may have a total oil volume of 40-50 cubic meters and may have a weight of up to 30-40 tons.

For conventional power transformers in the upper power range, transport often occurs with a tank without oil. It happens that the external design of the transformer must be adapted to the current transport profile, that is for any passage of bridges, tunnels etc..

Here follows a short summary of what can be described as limitation and problem areas according to prior art with respect to oil-filled power transformers:

An oil-filled conventional power transformer

- comprises an outer tank which is to house a transformer comprising a transformer core with coils, oil for insulation and cooling, mechanical bracing devices of various kinds etc. Very large mechanical demands are placed on the tank, since, without oil but with a transformer, it shall be capable of being vacuum-treated to practically full vacuum. The need for an external tank require very extensive manufacturing and testing processes. Furthermore, the tank means that external measures of the transformer become much larger than for a so called "dry" transformer for the same power. The larger external measures also normally entail considerable transport problems.

- normally comprises a so called pressure-oil-cooling. This cooling method requires access to an oil pump, an external cooling element, an expansion vessel and an expansion coupling etc.

- comprises an electrical connection between the external connections of the transformer and the immediately connected coils/windings in the form of a bushing fixed to the tank. The bushing is designed to withstand any insulation requirements made, both regarding the outside and the inside of the tank.

- comprises coils/windings whose conductors are divided into a number of conductor elements, strands, which have to be transposed in such a way that the voltage induced in each strand becomes as identical as possible and such that the difference in induced voltage between each pair of strands becomes as small as possible.

- comprises an insulation system, partly within a coil/winding and partly between coils/windings and other metal parts, which system is designed as a solid cellulose or warnish-based insulation nearest the individual conductor element and, outside of this, solid cellulose and a liquid, possibly also gaseous, insulation. In addition, it is extremely important that the insulation system exhibits a very low moisture content.

- comprises as an integrated part an on-load tap changer, surrounded by oil and normally connected to the high voltage winding of the transformer for voltage control.

- involves a non-negligeable fire hazard in connection with internal partial discharges, so called corona, sparking in on-load tap changers and other fault conditions.

- comprises normally a monitoring device for monitoring gas dissolved in the oil, which occurs in case of electrical discharges therein and in case of local increases of the temperature.

- may result, in the event of damage or accident, in oil spillage leading to extensive environmental damage.

OBJECT OF THE INVENTION

The primary object of the present invention is to devise ways to design the device and the method so as to achieve better protection for the object and, accordingly, a reduced load on the same, a fact which means that the object itself does not have to be designed to withstand a maximum of short-circuit currents/fault currents during relatively long time periods.

A secondary object with the invention is to design the protection device and method such that an adequate protection is achieved for electric objects in the form of transformers and reactors, the design of which is based upon non-conventional design principles, which may mean that the design does not have the same resistance to fault-related over-currents, internal as well as external, as the conventional present day conventional transformers and reactors. However, the invention is of course also intended to be applicable in connection with conventional transformers and reactors.

SUMMARY OF THE INVENTION

According to the invention, the object indicated above is achieved in that the line between the object and the switching device is connected to an overcurrent reducing arrangement, which is actuatable for overcurrent reduction with assistance of an overcurrent conditions detecting arrangement within a time period substantially less than the break time of the switching device, and that between the connection of the overcurrent reducing arrangement to the line and the object, there is provided a current limiter.

Thus, the invention is based upon the principle not to rely for breaking purposes only upon a switching device which finally establishes galvanic separation, but in-

stead use a rapidly operating overcurrent reducing arrangement, which, without effecting any real breaking of the overcurrent, nevertheless reduces the same to such an extent that the object under protection will be subjected to substantially reduced strains and, accordingly, a smaller amount of damage. The reduced overcurrent/fault current means, accordingly, that when the switching device establishes galvanic separation, the total energy injection into the protected object will have been much smaller than in absence of the overcurrent reducing arrangement. Besides, there will a further reduction of the fault current flowing to (or from) the object by means of the current limiter. Also the current limiter is of such a nature that it is rapidly operating for current reduction to such an extent that the strains imposed on the object will be dramatically reduced without the current limiter having to effect any total breaking of the overcurrent/fault current.

According to a preferred embodiment of the invention, the overcurrent reducing arrangement is designed as comprising an overcurrent diverter for diversion of overcurrents to earth or otherwise another unit having a lower potential than the network/equipment.

The current limiter according to the invention is suitably based on current limitation by means of a constant or variable inductance and/or resistance or other impedance.

As is more closely defined in the claims, the invention is applicable on transformers and reactors constructed by means of unconventional technique, namely cable technology. These may under certain conditions become sensitive to electric faults. Such a design may for instance be given a lower impedance than what is considered con-

ventional today within the power field. This means that the design does not have the same resistance against fault-related overcurrents, internal as well as external, as the conventional apparatus of today. If the apparatus, besides, has been designed from the start to operate with a higher electrical voltage than the conventional apparatus of today, the strain on the electrical insulation system of the apparatus, caused by the resulting higher electrical field, becomes, of course, greater. This means that the apparatus may be more efficient, more economical, mechanically lighter, more reliable, less expensive to produce and generally more economical than conventional apparatus and may manage without the usual connection to other electromagnetic apparatus, such an apparatus requires an adequate electric protection to eliminate, or at least reduce, the consequences of a breakdown in the apparatus in question. A combination of the protection device according to the invention and an apparatus designed in this way, preferably a transformer or reactor, means an optimization of the plant in its entirety.

The non-conventional transformer intended here is a power transformer with a rated power of from a few hundred kVA up to over 1000 MVA with a rated voltage of from 3-4 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher, and which does not entail the disadvantages, problems and limitations which are associated with the prior art oil-filled power transformer according to what appears above.

The invention is based on the realization that by designing at least one winding in the trasformer/reactor such that it comprises a solid insulation surrounded by an outer and and an inner potential-equalizing semiconducting layer, within which inner layer the at least one electric

conductor is disposed, a possibility is provided of maintaining the electric field in the whole plant within the conductor. The electric conductor is, according to the invention, suitably so arranged that it has such conducting contact with the inner semiconducting layer that no harmful potential differences may arise in the boundary layer between the innermost part of the solid insulation and the semiconducting layer located inwardly thereof. Such a power transformer exhibits great advantages relative to a conventional oil-filled transformer. As mentioned by way of introduction, the invention also provides for the concept to be applied to reactors both with and without a core of magnetic material.

The essential difference between conventional oil-filled power transformers/reactors and a power transformer/reactor according to the invention is that the winding/windings thus comprise a solid insulation surrounded by external and internal potential layers as well as at least one electric conductor arranged inwardly of the inner potential layer, said potential layers being made from a semiconducting material. The definition of what is comprised by the concept semiconductor will be described below. According to a preferred embodiment, the winding/windings is/are designed in the form of a flexible cable.

At the high voltage levels which are required in a power transformer/reactor according to the invention, which is connected to high-voltage networks with very high operating voltages, the electric and thermal loads which may arise will impose extreme demands on the insulating material. It is known that so called partial discharges, pd, generally constitute a serious problem for the insulating material in high-voltage installations. If cavities, pores or the like arise at an insulating layer, internal corona

discharges may arise at high electric voltages, whereby the insulating material is gradually degraded, which finally may lead to electric break-down through the insulation. It is realized that this can lead to serious break-down of, for example, a power transformer.

The invention is, inter alia, based on the realization that it is of extreme importance that the semiconducting potential layers exhibit similar thermal properties and that the layers are firmly connected to the solid insulation. The thermal properties in view here relate to coefficient of thermal expansion. The inner and outer semiconducting layers and the intermediate insulation should, accordingly, be well integrated, i.e. in good contact with each other over substantially the entire boundary layer, independently of the temperature changes occurring at different loads. Thus, the insulation including the surrounding semiconducting layers will, at temperature gradients, constitute a monolithic part and defects caused by different temperature expansion in the insulation and the surrounding layers do not arise. The electric load on the material is reduced as a consequence of the fact that the semiconducting layers around the insulation will constitute equipotential surfaces and that the electric field in the insulation will hence be distributed uniformly over the insulation.

According to the invention, it must be ensured that the insulation is not broken down by the phenomena described above. This can be achieved by using as insulation system semiconducting layers and intermediate insulation layer produced in such a way that the risk for cavities and pores is minimal, for example extruded layers of a suitable plastic material, such as XLPE (cross linked polyethylene) and EP-rubber (EP = ethylene-propylene). The insu-

lating material is thus a low-loss material with high break-down strength.

It is known that transmission cables for high voltage are designed with conductors having an extruded insulation with an inner and outer semiconducting layer. In transmission of electrical energy, one has since long ago aimed at avoiding defects in the insulation. However, in high voltage transmission cables the electric potential along the length of the cable is not changed, but the potential lies, in principle, at the same level, which means a high electric stress on the insulating material. The transmission cable is provided with one inner and one outer semiconducting layer for potential equalization.

Thus, the winding is according to the invention provided with a solid insulation and surrounding potential equalizing layers, whereby the transformer/reactor may be obtained, in which the electrical field is retained within the winding. Additional improvements may also be achieved by constructing the conductor from smaller insulated parts, so-called strands. By making these strands small and circular, the magnetic field across the strands will exhibit constant geometry in relation to the field and the occurrence of eddy currents is minimized.

According to the invention the winding/windings is/are thus preferably made in the form of a cable comprising at least one conductor comprising a number of strands and an inner semiconducting layer around the strands. Outside of this inner semiconducting layer is the main insulation of the cable in the form of a solid extruded insulation, and around this insulation there is an outer semiconducting layer. The cable may in certain connec-

tions have additional outer and inner layers. For instance, further potential equalizing, semiconducting layers could be arranged in the solid insulation between those two layers which in this specification are denominated "inner" and "outer" In such a case, this additional layer will lie on a medium potential.

According to the invention, the outer semiconducting layer shall exhibit such electrical properties that a potential equalization along the conductor is ensured. The semiconducting layer may, however, not exhibit such conductivity properties that a current will be induced in the layer, said current causing an unwanted thermal load. However, the conducting properties of the layer must be sufficient to ensure that the outer layer is capable of forming an equipotential surface. The inner semiconducting layer must present a sufficient electrical conductivity to be able to operate potential-equalizing and, accordingly, equalizing with regard to the electrical field outside the inner layer. In this connection it is important that the layer has such properties that it equalizes irregularities in the surface of the conductor and so that the layer is capable of forming an equipotential surface with a high surface finish at the border layer to the rigid insulation. The inner layer may be formed with a varying thickness but in order to ensure an even surface with respect to the conductor and the solid insulation, the thickness of the layer should be between 0,5 and 1 mm. However, the inner layer may not exhibit such a high electrical conduction capacity that the layer contributes to induction of voltages.

The resistivity for the inner and outer layers should lie in the range 10^{-6} Ωcm - 100 kΩcm, suitably 10^{-3} - 1000 Ωcm, preferably 1-500 Ωcm. Furthermore, it is pre-

ferred that the inner and outer layers each exhibit a resistance, which per meter cable is in the range 50 μΩ - 5 MΩ.

Thus, such a XLPE cable or a cable with EP rubber insulation or a corresponding cable is used according to the invention in a modified embodiment and in an entirely new field of use as winding in a magnetic circuit.

A winding comprising such a cable will entail quite different conditions from the insulation point of view from those which apply to conventional transformers/reactor windings due to the electric field distribution. To utilize the advantages afforded by the use of the mentioned cable, there are other possible embodiment as regards grounding of a transformer/reactor according to the invention than that which is applicable for conventional oil-filled power transformers. These methods are the subject matter of separate application for patent.

It is essential and necessary for a winding in a power transformer/reactor according to the invention that at least one of the strands of the conductor is uninsulated and arranged such that good electrical contact is achieved with the inner semiconducting layer. Thus, the inner layer will always lie on the potential of the conductor.

As far the rest of the strands are concerned, all of them or some of them may be insulated, for example by being varnished.

Manufacturing transformer or reactor windings of a cable according to the above entails drastic differences as regards the electrical field distribution between conventional power transformers/reactors and a power trans-

former/reactor according to the invention. The decisive advantage with a cable-formed winding according to the invention is that the electric field is enclosed in the winding and that there is, thus, no electric field outside the outer semiconducting layer. The electric field achieved by the current-carrying conductor occurs in essential only in the solid main insulation. Both from the design point of view and the manufacturing point of view this means considerable advantages;

- The windings of the transformer may be formed without having to consider any electric field distribution and the transposition of strands, mentioned under the background art is omitted.

- The core design of the transformer may be formed without having to consider any electric field distribution.

- No oil is needed for electrical insulation of the winding, that is, the medium surround the winding may be air.

- No special connections are required for electrical connection between the outer connections of the transformer and the immediately connected coils/windings since the electrical connection, contrary to conventional plants, is integrated with the winding.

- The manufacturing and testing technology which is needed for a power transformer according to the invention is considerably simplier than for a conventional power transformer/reactor since the impregnation, drying and vacuum treatments described under the background art are not needed.

Further advantages and features of the invention, in particular with respect to the method according to the invention, appear from the following description and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the enclosed drawings, a more specific description of an embodiment example of the invention follows hereinafter.

In the drawings:

Fig 1	is a purely diagrammatical view illustrating the basic aspects behind the solution according to the invention,
Figs 2a-2d	are diagrams illustrating in a diagrammatical form and in a comparative way fault current developments and the energy development with and without the protection device according to the invention;
Fig 3	is a diagrammatical view illustrating a conceivable design of a device according to the invention;
Figs 4-9	are views partly corresponding to Fig 3 of different alternative embodiment of the invention with regard to the current limiter denoted 6;
Fig 10	is a diagrammatical view illustrating a possible design of the overcurrent reducing arrangement;

Fig 11 is a diagrammatical view illustrating the device according to the invention applied in connection with a power plant comprising a generator, a transformer and a power network coupled thereto;

Fig 12 shows the electric field distribution about a winding of a conventional power transformer/reactor;

Fig 13 shows an example of a cable used in the windings of the power transformers/reactors according to the invention, and

Fig 14 illustrates an embodiment of a power transformer according to the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An electric power plant comprising a protected object 1 is shown in Fig 1. As is described hereunder, this object could for instance consist of a transformer or reactor. This object is connected, via a line 2, to an external distribution network 3. Instead of such a network, the unit denoted 3 could be formed by some other equipment contained in the power plant. The power plant involved is conceived to be of such a nature that it is the object 1 itself which primarily is intended to be protected against fault currents from the network/equipment 3 when there occurs a fault in the object 1 giving rise to a fault current from the network/equipment 3 towards the object 1 so that the fault current will flow through the object. Said fault may consist in a short-circuit having been formed in the object 1. A short-circuit is a conduction path, which is not intended, between two or more points. The short-circuit may for instance consist of an arc. This

short-circuit and the resulting violent current flow may involve considerable damage and even a total break-down of the object 1.

It is already pointed out that with at least some types of protected electrical objects 1, short-circuit currents/fault currents harmful to the object in question may flow from the protected object towards the network/equipment 3. Within the scope of the invention, it is intended to be used for protection purposes not only for protection of the object from externally emanating fault currents flowing towards the object but also from internal fault currents in the object flowing in the opposite direction. This will be discussed in more detail in the following.

In the following, the designation 3 will, to simplify the description, always be mentioned as consisting of an external power network. However, it should be kept in mind that some other equipment may be involved instead of such a network, as long as said equipment causes violent current flow through the object 1 when there is a fault.

A conventional circuit breaker 4 is arranged in the line 2 between the object 1 and the network 3. This circuit breaker comprises at least one own sensor for sensing circumstances indicative of the fact that there is an overcurrent flowing in the line 2. Such circumstances may be currents/voltages but also other indicating that a fault is at hand. For instance, the sensor may be an arc sensor or a sensor recording short circuit sound etc. When the sensor indicates that the overcurrent is above a certain level, the circuit breaker 4 is activated for breaking of the connection between the object 1 and the network 3. The circuit breaker 4 must, however, break the total short circuit current/fault current. Thus, the circuit

breaker must be designed to fulfil highly placed requirements, which in practice means that it will operate relatively slowly. In Fig 2a it is illustrated in a current/time-diagram that when a fault, for instance a short circuit in the object 1, occurs at the time t_{fault}, the fault current in the line denoted 2 in Fig 1 rapidly assumes the magnitude i_1. This fault current i_1 is broken by means of the circuit breaker 4 at t_1, which is at least within 150 ms after t_{fault}. Fig 2d illustrates the diagram $i^2 \cdot t$ and, accordingly, the energy developed in the protected object 1 as a consequence of the short circuit therein. The energy injection into the object occurring as a consequence of the short-circuit current is, accordingly, represented by the total area of the outer rectangle in Fig 2d.

It is in this connection pointed out that the fault current in Figs 2a-c and the currents in Fig 2d represent the envelope of the extreme value. Only one polarity has been drawn out in the diagram for the sake of simplicity.

The circuit breaker 4 is of such a design that it establishes galvanic separation by separation of metallic contacts. Accordingly, the circuit breaker 4 comprises, as a rule, required auxiliary equipment for arc extinguishing.

According to the invention the line 2 between the object 1 and the switching device 4 is connected to an arrangement reducing overcurrents towards the apparatus 1 and generally denoted 5. The arrangement is actuatable for overcurrent reduction with the assistance of an overcurrent conditions detecting arrangement within a time period substantially less than the break time of the circuit breaker 4. This arrangement 5 is, accordingly, designed such that it does not have to establish any galvanic separation. Therefore, conditions are created to very rapidly estab-

lish a current reduction without having to accomplish any total elimination of the current flowing from the network 3 towards the protected object 1. Fig 2b illustrates in contrast to the case according to Fig 2a that the overcurrent reducing arrangement 5 according to the invention is activated upon occurrence of a short circuit current at the time t_{fault} for overcurrent reduction to the level i_2 at the time t_2. The time interval $t_{fault}-t_2$ represents, accordingly, the reaction time of the overcurrent reducing arrangement 5. By the task of the arrangement 5 not to break but only reduce the fault current, the arrangement may be caused to react extremely rapidly, which will be discussed more closely hereunder. As an example, it may be mentioned that current reduction from the level i_1 to the level i_2 is intended to be accomplished within one or a few ms after unacceptable overcurrent conditions having been detected. It is then aimed at to accomplish the current reduction in a shorter time than 1 ms, and preferably more rapidly than 1 microsecond.

As appears from Fig 1, the device comprises a current limiter generally denoted 6 and arranged in the line 2 between the connection of the arrangement 5 to the line 2 and the object 1. This current limiter is adapted to operate for current limitation primarily in a direction towards the object 1 but in certain fault cases also in a direction away from the object. The current limiter 6 may be arranged to be brought into operation for current limitation as rapidly as or even more rapidly than the overcurrent reducing arrangement 5. According to a further alternative involving less strain on the current limiter 6, the current limiter could be designed to be activated for current limitation not until the over-current from the network 3 towards the object 1 has been reduced by means of the over-current reducing arrangement 5, but of course the current limiter 6 should be brought to activity for

current limitation substa rly than the time when the circuit breake m that stated it appears that it is suitab rent limiter 6 is coupled to the line 2 in it is the current reduced by means of the ucing arrangement which in an even more red flow through the current limiter 6.

Fig 2b illustrates the ac ent limiter 6. In said Figure it has been ate that the current limiter 6 enters in r current limitation at the time t_3, whic e would mean that the duration of the curr by means of the over-current reducing arr een substantially limited, namely to the t_3. It is again pointed out that the rep Fig 2 are to be considered as purely diag time t_3, when the current limiter 6 is act much earlier and even earlier than the t ion of the over-current reducing arrangem me t_2. It appears from Fig 2b that the fau r the time t_3 is reduced to the level i_3. fault current i_3 is finally broken by mea t breaker 4 at a time t_1. However, the fau so comparatively small as a consequence ensioning of the current limiter 6 that t in question may be endured by the object also other parts of the power plant. The the reduction and limitation respectively rrent, which the energy injection from the sed by said fault current will give rise t cted object 1 is represented by the surfac g 2d with oblique lines. It appears that a on of the energy injection is achieved. I on it is pointed out that since, according model, the energy increases with the squar , a reduction by

one half of the cuhe energy injection to a fourth. It is illusc that the fault current will tend to flow vice 5. That part i_3 of the total fault cuh will continue to flow through the currenter the time t_3 is also marked in Fig 2c.

In reality, the dime arrangement 5 and the current limiter 6 ibe carried out such that the arrangement 5 it current and the voltage to be restrictethe current limiter 6 to substantially loweristic activation time as far as the current concerned is 1 ms, the dimensioning possible to carry out such that the current 1 sed to delimit the current not until afment 5 has reduced the current flowing ther 6 to at least a substantial degree. Ashis is not a requirement but the opposite cae possible.

It is illustrated in Fig 3 how the device may be realized. It that the invention is applicable in direso HVDC = High Voltage Direct Current) andrrent connections. In a multi phase arrangenating current, the line denoted 2 may be corming one of the phases in a multi phase aent system. However, it should be noted thacording to the invention may be realized so phases are subjected to the protecting functo the invention in case of a detected erroy that or those phases where a fault curreis subjected to current limitation.

It appears from Fivercurrent reducing arrangement generallymprises an overcurrent

diverter 7 for diverting overcurrents to earth 8 or otherwise another unit having a lower potential than the network 3. Thus, the overcurrent diverter may be considered as forming a current divider which rapidly establishes a short circuit to earth or otherwise a low potential 8 for the purpose of diverting at least a substantial part of the current flowing in the line 2 so that said current does not reach the object 1 to be protected. If there is a serious fault in the object 1, for instance a short circuit, which is of the same magnitude as the short circuit that the overcurrent diverter 7 is capable of establishing, it may be said that generally speaking a reduction to one half of the current flowing to the object 1 from the network 3 is achieved as a consequence of the overcurrent diverter 7 in case the fault is close to the latter. In comparison with Fig 2b, it appears, accordingly, that the current level i_2 illustrated therein and being indicated to amount to approximatively half of i_1 may be said to represent the worst occurring case. Under normal conditions, the purpose is that the overcurrent diverter 7 should be able to establish a short circuit having a better conductivity than the one corresponding to the short circuit fault in the object 1 to be protected so that accordingly a main part of the fault current is diverted to earth or otherwise a lower potential via the overcurrent diverter 7. It appears from this that, accordingly, in a normal fault case, the energy injection into the object 1 in case of a fault becomes substantially smaller than that which is indicated in Fig 2d as a consequence of lower current level i_2 as well as shorter time span t_2-t_3.

The overcurrent diverter 7 comprises switch means coupled between earth 8 or said lower potential and the line 2 between the object 1 and the network 3. This switch means comprises a control member 9 and a switch member 10. This switch member may for instance be formed by at least one

semiconductor component, for instance a thyristor, which is open in a normal state, i.e. isolating in relation to earth, but via the control member 9 may be brought into an active, conducting state in a very short time in order to establish current reduction by diversion to earth.

Fig 3 also illustrates that an overcurrent conditions detecting arrangement may comprise at least one and preferably several sensors 11-13 suitable for detecting such overcurrent situations requiring activation of the protection function. As also appears from Fig 3, these sensors may include the sensor denoted 13 located in the object 1 or in its vicinity. Furthermore, the detector arrangement comprises a sensor 11 adapted to sense overcurrent conditions in the line 2 upstreams of the connection of the overcurrent reducing arrangement 5 and the line 2. As is also explained in the following, it is suitable that a further sensor 12 is provided to sense the current flowing in the line 2 towards the object 1 to be protected, i.e. the current which has been reduced by means of the overcurrent reducing arrangement 5. In addition, it is pointed out that the sensor 12, as well as possibly the sensor 13, is capable of sensing the current flowing in the line 2 in a direction away from the object 1, for instance in cases where energy magnetically stored in the object 1 gives rise to a current directed away from the object 1.

It is pointed out that the sensors 11-13 do not necessarily have to be constituted by only current and/or voltage sensing sensors. Within the scope of the invention, the sensors may be of such nature that they generally speaking may sense any conditions indicative of the occurrence of a fault of the nature requiring initiation of a protection function.

In cases where such a fault occurs that the fault current will flow in a direction away from the object 1, the device is designed such that the control unit 14 thereof will control the further breaker 6 to closing, in case it would have been open, and, in addition, the overcurrent reducing arrangement 5 is activated such that the short circuit current may be diverted by means of the same. When, for example, the object 1 is conceived to consist of a transformer, the function on occurrence of a short circuit therein could be such that the short circuit first gives rise to a violent flow of current into the transformator, which is detected and gives rise to activation of the arrangement 5 for the purpose of current diversion. When the current flowing towards the transformer 1 has been reduced in a required degree, the current limiter 6 is caused to reduce the current, but, controlled by means of the control unit 14, possibly not earlier than leaving time for the energy, in occurring cases, magnetically stored in the generator 1 to flow away from the generator 1 and be diverted via the arrangement 5.

Furthermore, the device comprises a control unit generally denoted 14. This is connected to the sensors 11-13, to the overcurrent reducing arrangement 5 and to the current limiter 6. The operation is such that when the control unit 14 via one or more of the sensors 11-13 receives signals indicating occurrence of unacceptable fault currents towards the object 1, the overcurrent reducing arrangement 5 is immediately controlled to rapidly provide the required current reduction. The control unit 14 may be arranged such that when the sensor 12 has sensed that the current or voltage has been reduced to a sufficient degree, it controls the current limiter 6 to obtain operation thereof for breaking when the overcurrent is below a predetermined level. Such a design ensures that the current limiter 6 is not caused to limit the current until

the current really has been reduced to such a degree that the current limiter 6 is not given the task to break such a high current that it is not adequately dimensioned for that purpose. However, the embodiment may alternatively also be such that the current limiter 6 is controlled to limit the current a certain predetermined time after the overcurrent reducing arrangement having been controlled to carry out current reduction.

The circuit breaker 4 may comprise a detector arrangement of its own for detection of overcurrent situations or otherwise the circuit breaker may be controlled via the control unit 14 based upon information from the same sensors 11-13 also controlling the operation of the overcurrent reducing arrangement.

In the embodiment illustrated in Fig 3 the current limiter 6 is formed by an inductance 27 provided in the line 2. Such an inductance achieved by means of a coil has the result that at a certain increase of the current, a back electromotive force arises, which counteracts increase of current. An advantage with this embodiment is that it is extremely simple and furthermore, it gives rise to, when a fault occurs, a rapid limitation of the current flow towards the object 1 without need for active control.

As the device has been described until now, it operates in the following way: In absence of a fault, the circuit breaker is closed whereas the switch means 10 of the overcurrent reducing arrangement 5 is open, i.e. in a non-conductive state. In this situation the switch means 10 must, of course, have an adequate electrical strength so that it is not unintentionally brought into a conducting state. Over-voltage conditions appearing in the line 2 as a consequence of athmospheric (lightning) circumstances or coupling measures may, thus, not cause the voltage

strength of the closing means 10 in its non-conducting state to be exceeded. For this purpose, it is suitable to couple at least one surge arrester 22 in parallel over the switch means 10. In the example, such surge arresters are illustrated on either side of the switch means 10. The surge arresters have, accordingly, the purpose to divert such over-voltages which otherwise could risk to cause inadvertent breakthrough in the switch means 10.

When an over-current state has been registered by any of the sensors 11-13 or the own sensor of the circuit breaker 4 (it is of course understood that information from the own sensor of the circuit breaker 4 can be used as a basis for control of the over-current reducing arrangement 5 according to the invention) and this over-current state is of such magnitude that a serious fault of the object 1 can be expected to be present, the breaking function is initiated as far as the circuit breaker 4 is concerned. In addition, the control unit 14 controls the over-current reducing arrangement 5 to effect such reduction, and this more closely by causing the switch means 10 into an electrically conducting state via control member 9. As described before, this may occur very rapidly, i.e. in a fraction of the time required for breaking by the circuit breaker 4, for what reason the object to be protected immediately is relieved from the full short-circuit current from the network 3 by the switch means 10 diverting at least an important part and in practice the main part of the current to earth or otherwise a lower potential. The current limiter 6 may, as well, enter into a rapid function to limit the current flowing into the line 2 towards (or possibly from) the object 1.

When these indicents have occurred, breaking is carried out as the last measure by means of the circuit breaker 4. It is important to note that the over-current reducing

arrangement 5 as well as the current limiter 6 according to a first embodiment are designed to be able to function repeatedly. Thus, when it has been established by means of the sensors 11-13 that the circuit breaker 4 has closed the switch means 10 is reset into a non-conducting state, and the current limiter 6 is ready, so that the next time the circuit breaker 4 closes, the protective device is in a completely operational state. According to another embodiment, the arrangement 5 may require exchange of one or more parts in order to operate again.

Fig 4 illustrates an alternative embodiment of the current limiter 6a. This embodiment comprises an inductance 28 and a capacitor 29, which form, in unison, a resonance circuit, which at resonance gives a very high impedance. The inductance and the capacitor are coupled parallel to each other. A switch 30 and the capacitor 29 are coupled in parallel over the inductance 28 placed in the line 2. Accordingly, the switch 30 and the condensator 29 are coupled inparallel over the inductance 28 placed in the line 2. Accordingly, the switch 30 and the condensator 29 are placed in series with each other. The coupler 30 has one or more contacts, which by means of a suitable operating member 31 may be controlled for closing or opening respectively via the control unit 14.

The current limiter 6a illustrated in Fig 4 operates in the following way: during normal operational conditions, the switch 30 is open. The impedance of the current limiter 6a is given by the inductance and the resistance of the inductor. In case of a fault current of a sufficient magnitude, the control unit 14 will control the switch means 10 for closing for the purpose of overcurrent diversion and furthermore, the control unit 14 will control the switch 30 to closing such that the capacitor 29 is coupled in and a parallel resonance circuit, which

should be adjusted to the power frequency, is formed. The impedance of the current limiter 6a will be very high at resonance. As is also apparent from a comparative study of Fig 2b, a considerable current reduction down to the drawn current level i_3 is obtained.

In Fig 5 an alternative embodiment of the current limiter 6b is shown, this embodiment being based upon a series resonance circuit comprising an inductance 32 and a capacitor 33 in series with each other and a switch 34 coupled in parallel over the capacitor 33. An operating member 35 for operating the contact or contacts of the switch 34 is under control from the control unit 14. During normal operation, the switch 34 over the capacitor 33 is open. The coil 32 in series with the capacitor 33 in series resonance (at for example 50 Hz) has a very small impedance. Transient fault currents are blocked by the coil 32. In case of a fault, the voltage over the capacitor as well as the inductance is increased. By closing the switch 34 over the capacitor, the same is shortcircuited. This involves a drastic increase of the total impedance, for what reason the current is limited.

As is indicated in Fig 5, the inductance 32 may be made variable, for instance by short-circuiting parts of the winding or a winding located on the same core. In this way it becomes possible to continuously adjust the current limiter 6b to minimize the voltage drop over the current limiter during normal load. Another modification not shown in Fig 5 is to use a self-triggered spark gap instead of the switch 34 over the capacitor 33. In this way, a self-triggered function is achieved, i.e. the embodiment becomes passive in the sense that no particular control from any control unit is required.

In the variant illustrated in Fig 6, the current limiter 6c comprises a switch 36 arranged in the line 2 and in parallel over this switch a capacitor 37 and a resistor 38, the capacitor and resistor being coupled in parallel relative to each other. The switch 36 has in reality the character of a vacuum circuit breaker provided with transversely directed coils 39 to increase the arc voltage and achieve current commutation into the limiting resistor 38. The control unit 14 is arranged to control the switch 36 via an operating member 40.

Fig 7 illustrates a current limiter 6d formed by a mechanical switch 41 having a commutation element 42 consisting of a large number of series-connected arc chambers. The arc chambers are made of a resistive material. When the switch 41 opens, the arc short-circuits the resistive arc chamber. When the arc moves into the arc chamber, the arc is divided into many subarcs. In this way the arcs are increasing the length of the resistive path between the contacts and an increasing resistance is achieved.

As before, the control unit 14 is arranged to control the operation of the switch 41 via an operating member 43.

Fig 8 illustrates a further embodiment of a current limiter 6e. This limiter comprises, in the embodiment, a fast semiconductor switch 44 and a parallel current-limiting impedance 45 and a voltage-limiting element 46, for instance a varistor. The semiconductor switch 44 may be formed by means of gate turn-off thyristors (GTO thyristors). A resistor is used as a current limiting impedance. The varistor 46 limits the over-voltage when the current is restricted. Under normal load conditions, the current flows through the semiconductors 44. When a

fault is detected, the semiconductor switch 44 is opened under control via the control unit 14, preferably via a suitable operating member 47, and the current is commutated to the resistor 45.

Finally, a current limiter 6f is illustrated in Fig 9, this limiter comprising a coil 48 connected in the line 2. The coil 48 is included in a reactor having an iron core 49. Between the iron core 49 of the reactor and the coil 48 there is provided a superconducting tubular screen 50. Under normal operation, the superconducting screen 50 screens-off the iron core from the coil, the inductance thus being relatively low. When the current exceeds a certain level, the superconduction ceases and the inductance increases drastically. Thus, a strong current limitation is obtained.

In the embodiment according to Fig 9, the screening of the iron core from the coil occurs due to the Meissner-effect. An advantage with the embodiment according to Fig 9 is, as far as current limiter 6f is concerned, that a small inductance is at hand in normal operation. A disadvantage is that in order to achieve superconduction, cooling to very low temperatures, for instance by liquid nitrogen, is required.

In all embodiments Figs 4-9 just described, only the differences with respect to the current limiter relative to the design according to Fig 3 have been described more closely. With respect to other constituents, the description relating to Fig 3 is referred to.

Fig 10 illustrates an alternative embodiment of the overcurrent reducing arrangement 5. Instead of relying on a semiconductor switch means as in Fig 3, the embodiment according to Fig 10 is intended to involve causing of a

medium present in a gap 24 between electrodes 23 to assume electrical conductivity by means of a control member 9a. This control member is arranged to control the operation of members 25 for causing or at least initiating the medium or a part thereof in the gap 24 into a conducting state. Said member 25 is in the example arranged to cause the medium in the gap 24 to assume electrical conductivity by causing or at least assisting in causing the medium to ionization/plasma. It is preferred that the members 25 comprise at least one laser, which by energy supply to the medium in the gap 24 provides for the ionization. As appears from Fig 10, a mirror 26 may be used for necessary diverting of the laser beam bundle. It is in this connection pointed out that the embodiment according to Fig 10 may be such that the means 25 do not alone give rise to ionization/plasma in the entire electrode gap. Thus, the intention may be that an electrical field imposed over the gap should contribute in ionization/plasma formation, only a part of the medium in the gap being ionized by means of the members 25 so that thereafter the electrical field in the gap gives rise to establishment of plasma in the entire gap. It is in this connection pointed out that there may be in the electrode gap not only a medium consisting of various gases or gas mixtures but also vacuum. In the case of vacuum, initiation by means of laser occurs at at least one of the electrodes, which, accordingly, will function as an electrone and ion transmitter for establishment of an ionized environment/a plasma in the electrode gap.

Fig 11 illustrates a conventional embodiment in the sense that a generator 1b via a transformer 1a is coupled to a power network 3a. The objects to be protected are, accordingly, represented by the transformer 1a and the generator 1b. The over-current reducing arrangement 5a and the current limiter 6g and the ordinary circuit breaker 4a are,

as can be seen, arranged similar to what appears from Fig 1 for the case that the object 1 shown therein is conceived to form the object 1a according to Fig 11. Accordingly, reference is in this regard made to the descriptions delivered with respect to Fig 1. The same is due for the protection function of the over-current reducing arrangement 5c and the current limiter 6i with respect to the generator 1b. In this case, the generator 1b could, accordingly, be considered equivalent with the object 1 in Fig 1 whereas the transformer 1a could be considered equivalent to the equipment 3 in Fig 1. Thus, the over-current reducing arrangement 5c and the current limiter 6i will, in combination with the conventional circuit breaker 4b, be able to protect the generator 1b against violent flow of current in a direction away from the transformer 1a.

As an additional aspect in Fig 11, the additional over-current reducing arrangement 5b with associated current limiter 6h are present. As can be seen, there will be over-current reducing arrangements 5a and 5b on either side of the transformer 1a. It is then pointed out that the current limiters 6g and 6i respectively are arranged in the connections between said over-current reducing arrangements 5a and 5b and the transformer 1a. The further over-current reducing arrangement 5b is intended to protect the transformer 1a from current flows towards the transformer from the generator 1b. As can be seen, the circuit breaker 4b will be able to break independently of in which direction between the objects 1a and 1b a protection function is desired.

With the assistance of Figs 12-14 an embodiment according to the invention in the form of a non-conventional design of a transformer/reactor will now be described.

Fig 13 shows an example of a cable which may be used in the windings which are included in dry power transformers reactors according to the invention. Such a cable comprises at least one conductor 54 consisting of a number of strands 55 with an inner semiconducting layer 56 arranged around the strands. Outside this inner semiconducting layer is the main insulation 57 of the cable in the form of a solid, suitably extruded insulation and surrounding this solid extruded insulation an outer semiconducting layer 58. The cable may, as mentioned previously, be provided with other additional layers for special purposes, for example for preventing too high electric stresses on other regions of the transformer/reactor. From the point of view of geometrical dimensions, the cables in question will have a conductor area which is between 80 and 3000 mm^2 and an outer cable diameter which is between 20 and 250 mm.

The windings of a power transformer/reactor manufactured from the cable described above may be used both for single phase, three phase and poly phase transformers/reactors independently of how the core is shaped. One embodiment is shown in Fig 14, which illustrates a three phase laminated core transformer. The core comprises, in conventional manner, three core limbs 59, 60 and 61 and the retaining yokes 62 and 63. In the embodiment shown, both the core limbs and the yokes have a tapering cross section.

Concentrically around the core limbs, the windings formed with the cable are located. The embodiment shown in Fig 14 has, as can be seen, three concentric winding turns 64, 65 and 66. The innermost winding turn 64 may represent the primary winding and the other two winding turns 15 and 16 may represent secondary windings. In order not to overload the figure with too many details, the connections of the windings are not shown. Otherwise the Figure shows that,

in the embodiment shown, spacing bars 67 and 68 with several different functions are disposed at certain points around the windings. The spacing bars may be formed of insulating material intended to provide a certain space between the concentric winding turns for cooling, bracing etc. They may also be formed of electrically conducting material in order to form part of the grounding system of the windings.

It should be noted that the description presented hereinabove only should be considered as exemplifying for the inventive idea, on which the invention is built. Thus, it is obvious for the man skilled in the art that detail modifications may be made without leaving the scope of the invention. As an example, it may be mentioned that it would be possible to use as a switch means 10 a mechanical switch.

Claims

1. A device in an electric power plant for protection of an object (1) connected to an electric power network (3) or another equipment included in the electric power plant from fault-related over-currents, the device comprising a switching device (4) in a line (2) between the object and the network/equipment, *characterized* in that the line (2) between the object and the switching device is connected to an over-current reducing arrangement (5), which is actuatable for over-current reduction with assistance of an over-current conditions detecting arrangement (11-13) within a time period substantially shorter than the break-time of the switching device, and that a current limiter (6) is arranged between the connection of the overcurrent reducing arrangement (5) to the line (2) and the object (1).

2. A device according to claim 1, *characterized* in that the switching device (4) is formed by a circuit-breaker.

3. A device according to claim 1 or 2, *characterized* in that the over-current reducing arrangement (5) comprises an over-current diverter (7) for diverting over-currents to earth (8) or otherwise another unit having a lower potential than the network/equipment.

4. A device according to claim 3, *characterized* in that the over-current diverter (7) comprises a switch means (10) coupled between earth or said lower potential and the line between the object (1) and the network/equipment (3).

5. A device according to claim 4, *characterized* in that the switch (10) comprises at least one semiconductor component.

6. A device according to claim 4, *characterized* in that the switch (10a) comprises an electrode gap (24) and means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity.

7. A device according to claim 6, *characterized* by said means (25) for causing or at least initiating the electrode gap to assume electrical conductivity being arranged to cause the gap or a part thereof to assume the form of a plasma.

8. A device according to claim 7, *characterized* by said members (25) for causing or at least initiating the electrode gap or a part thereof to assume electrical conductivity comprising at least one laser.

9. A device according to any preceding claim, *characterized* in that the current limiter (6) comprises at least one inductance and/or a resistance or another impedance.

10. A device according to any preceding claim, *characterized* in that the current limiter (6a, 6b) comprises an inductance (28; 32) and a capacitor (29; 33), which in unison form a resonance circuit providing high impedance at resonance.

11. A device according to claim 10, *characterized* in that the inductance (28) and capacitor (29) are coupled in parallel to each other.

12. A device according to claim 11, *characterized* in that a switch (30) and the capacitor (29) are coupled in parallel over the inductance (28) provided in the line.

13. A device according to claim 11, *characterized* in that the inductance (32) and capacitor (33) are coupled in series with each other.

14. A device according to claim 13, *characterized* in that an arrangement (34) short-circuiting the capacitor is connected in parallel over the capacitor (33).

15. A device according to claim 14, *characterized* in that the arrangement short-circuiting the capacitor is formed by a switch (34).

16. A device according to claim 14, *characterized* in that the arrangement short-circuiting the capacitor is formed by a spark gap.

17. A device according to claim 9, *characterized* in that the current limiter (6c) comprises a switch (36) arranged in the line (2) and a capacitor (37) and resistor (38) coupled parallel to the switch and to each other.

18. A device according to claim 9, *characterized* in that the current limiter (6d) comprises a switch (41) arranged in the line and a commutating arrangement (42) comprising at least one resistive arc chamber.

19. A device according to claim 9, *characterized* in that the current limiter (6e) comprises a switch (44) arranged in the line and a current-limiting impedance (45) coupled parallel over the switch, a current-limiting element (46) being coupled parallel over the impedance.

20. A device according to claim 9, *characterized* in that the current limiter (6f) comprises a coil (48) coupled in the line, said coil being included in a reactor with an iron core (49), that a super-conducting tubular

screen (50) is provided between the iron core of the reactor and the coil, the super-conducting screen screening the iron core from the coil under normal operation, the inductance thus being relatively low, whereas when the current exceeds a certain level, super conduction ceases and the inductance increases drastically.

21. A device according to any preceding claim, *characterized* in that the current limiter is arranged to be activated for current limitation when overcurrent conditions have been detected.

22. A device according to claim 21, *characterized* by a control unit (14) arranged to activate the current limiter based on information from the arrangement detecting overcurrent conditions.

23. A device according to claim 22, *characterized* in that the control unit (14) is adapted to activate the current limiter by operation of the switch defined in claim 12, 15, 18 or 19.

24. A device according to any preceding claim, *characterized* in that the current limiter is adapted to be activated for current limitation after reduction of the overcurrent towards or away from the object (1) by means of the overcurrent reducing arrangement (5) but substantially more early than the switching device.

25. A device according to any of claims 22-24, *characterized* in that the control unit (14) is adapted to provide activation of the current limiter when the overcurrent towards or away from the object (1) is indicated to be under a predetermined level by the detecting arrangement.

26. A device according to any preceding claim, *characterized* in that two overcurrent reducing arrangements are arranged on either sides of the object to protect the same from two sides.

27. A device according to claim 1, *characterized* in that it comprises a control unit (14) connected to the overcurrent reducing arrangement (5) and to the arrangement (11-13) detecting overcurrent conditions, said control unit being arranged to control the overcurrent reducing arrangement to close with the assistance of information from the arrangement detecting overcurrent conditions when justified by protection reasons.

28. A device according to claim 22, 23, 25 or 27, *characterized* in that one and the same control unit (14) is adapted to control the overcurrent reducing arrangement (5) and the current limiter (6) based upon information from the arrangement (11-13) detecting overcurrent conditions.

29. A device according to any preceding claim, *characterized* in that the protected object (1) is formed by an electric apparatus with a magnetic circuit.

30. A device according to claim 29, *characterized* in that the object is formed by a transformer or reactor.

31. A device according to any of claims 29-30, *characterized* in that the electric apparatus provided with magnetic circuit is designed for high voltage, suitably 72.5 kV and more.

32. A device according to any of claims 29-31, *characterized* in that the magnetic circuit of the electric

apparatus comprises a winding formed by means of a cable.

33. A device according to any of claims 29-32, *characterized* in that at least one winding of the apparatus comprises at least one conductor (54) and around this conductor an electric insulation (57) of a solid insulation material, that an outer layer (58) of a semiconducting material is arranged around the insulation, that an inner layer (56) of a semiconducting material is arranged inwardly of the insulation (57) and that said at least one conductor (54) is arranged inwardly of the inner layer (56).

34. A device according to claim 33, *characterized* in that at least one of the inner and outer layers (56, 58) have substantially equal thermal coefficient of expansion as the insulation material.

35. A device according to any of claims 33 and 34, *characterized* in that the inner layer (56) is in electric contact with said at least one conductor (54).

36. A device according to any of claims 33-35, *characterized* in that the outer layer (58) essentially forms an equipotential surface.

37. A device according to any of claims 33-36, *characterized* in that the inner and outer semiconducting layers (56, 58) and the insulation (57) are bonded to each other over substantially the entire interface.

38. A device according to claim 33, *characterized* in that at least one of the strands (55) of the conductor (54) is uninsulated and arranged such that electrical contact is achieved with the inner semiconducting layer (56).

39. A device according to any of claims 33-38, *characterized* in that the cables are manufactured with a conductor area which is between 80 and 3000 mm^2 and with an outer cable diameter which is between 20 and 250 mm.

40. A device according to any of claims 30-39, *characterized* in that the object designed as a power transformer/reactor comprises a core formed by magnetic material and consisting of core limbs and yokes.

41. A device according to any of claims 29-40, *characterized* in that the power transformer/reactor is formed without a core (air-wound).

42. A device according to any of claims 29-41, comprising at least two galvanically separated windings, *characterized* in that the windings are concentrically wound.

43. Use of a device according to any preceding claim for protection of an object in the form of a transformer or reactor against fault-related overcurrents.

44. A method in an electric power plant for protection of an object (1) connected to an electric power network (3) or another equipment contained in the electric power plant from fault-related overcurrents, a switching device (4) being located in a line between the object and the network/equipment, *characterized* in that an overcurrent reducing arrangement (5) connected to the line between the object (1) and the switching device (4) is activated for overcurrent reduction when overcurrent conditions have been detected by means of an arrangement (11-13) for this purpose, within a time period substantially shorter than the break time of the switching device (4).

45. A method according to claim 44, *characterized* in that overcurrents are diverted to earth (8) or otherwise another unit having a lower potential than the network/equipment by means of the overcurrent reducing arrangement (5).

46. A method according to claim 44 or 45, *characterized* in that a current limiter (6), which is arranged in the line between the switching device and the object and between the overcurrent reducing arrangement (5) and the object (1), is caused to break not until the overcurrent towards or away from the object (1) has been reduced by means of the overcurrent reducing arrangement (5).

47. A method according to any of claims 44-46, *characterized* in that the protection device comprising the overcurrent reducing arrangement (5) is coupled for protection of an object in the form of a transformer or reactor.

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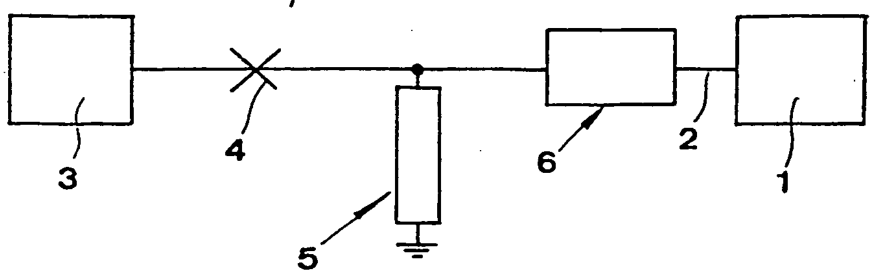

Fig 1

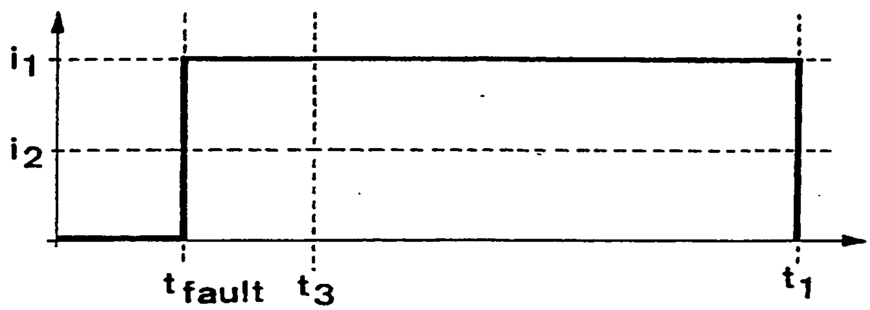

Fig 2a

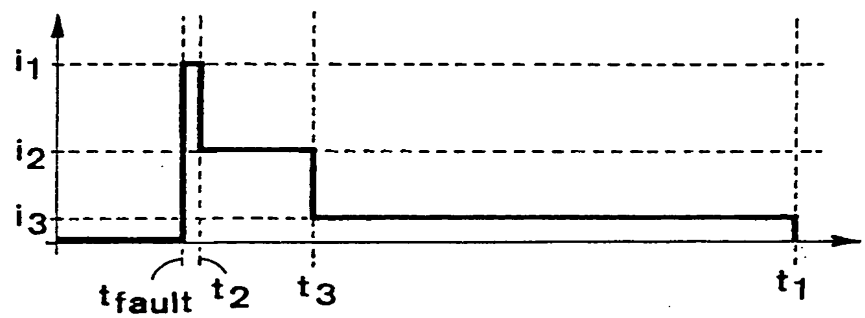

Fig 2b

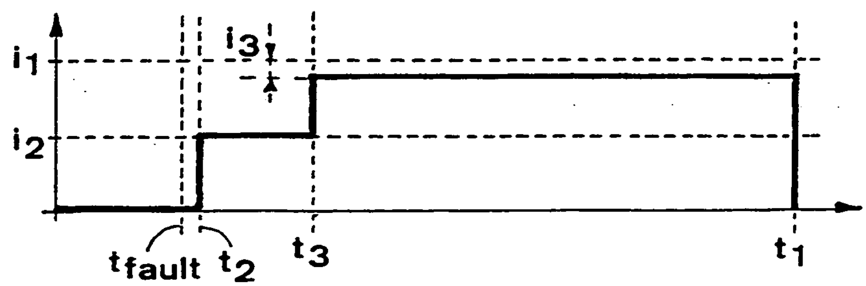

Fig 2c

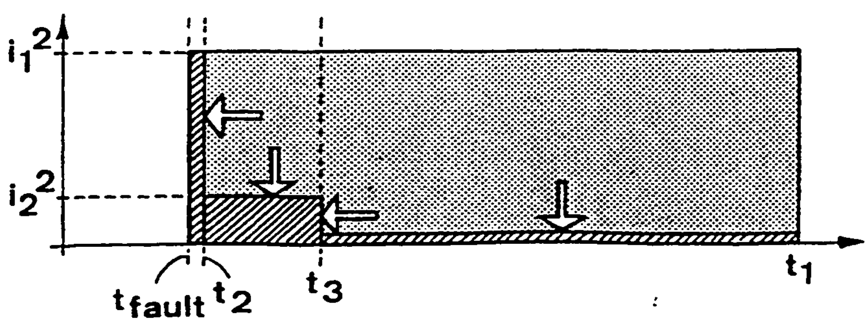

Fig 2d

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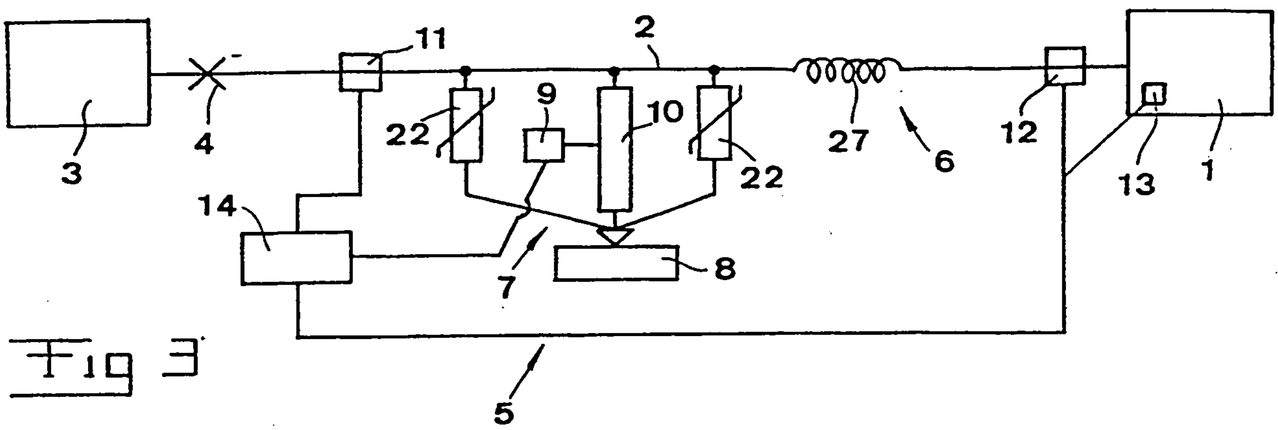

Fig 3

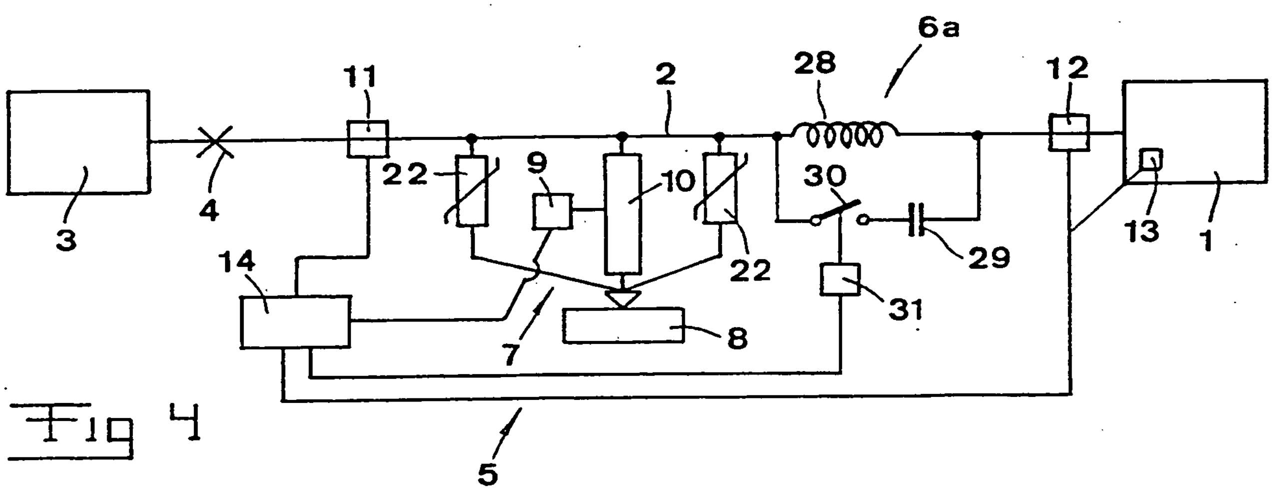

Fig 4

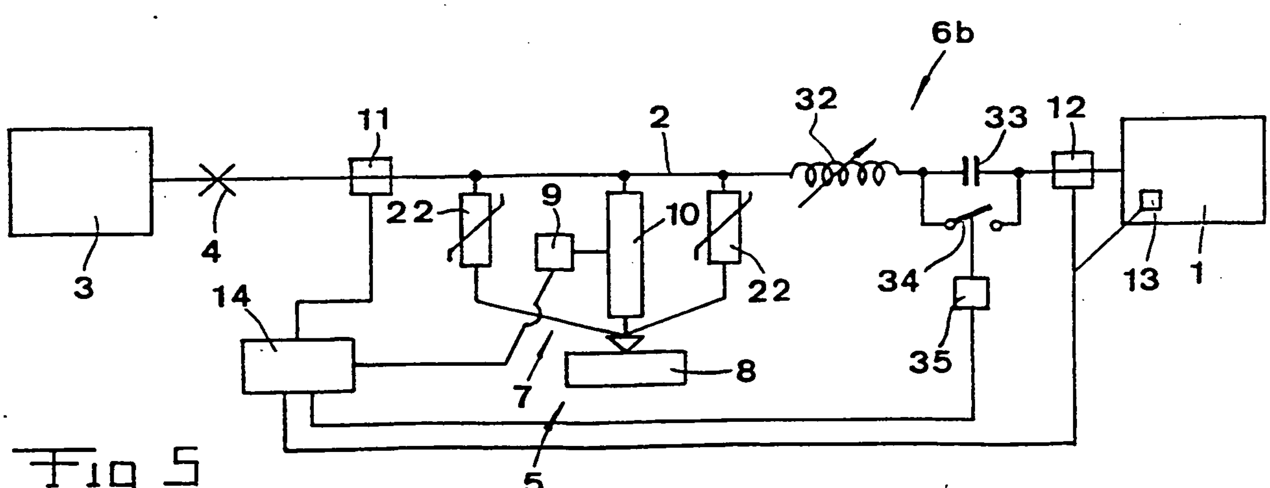

Fig 5

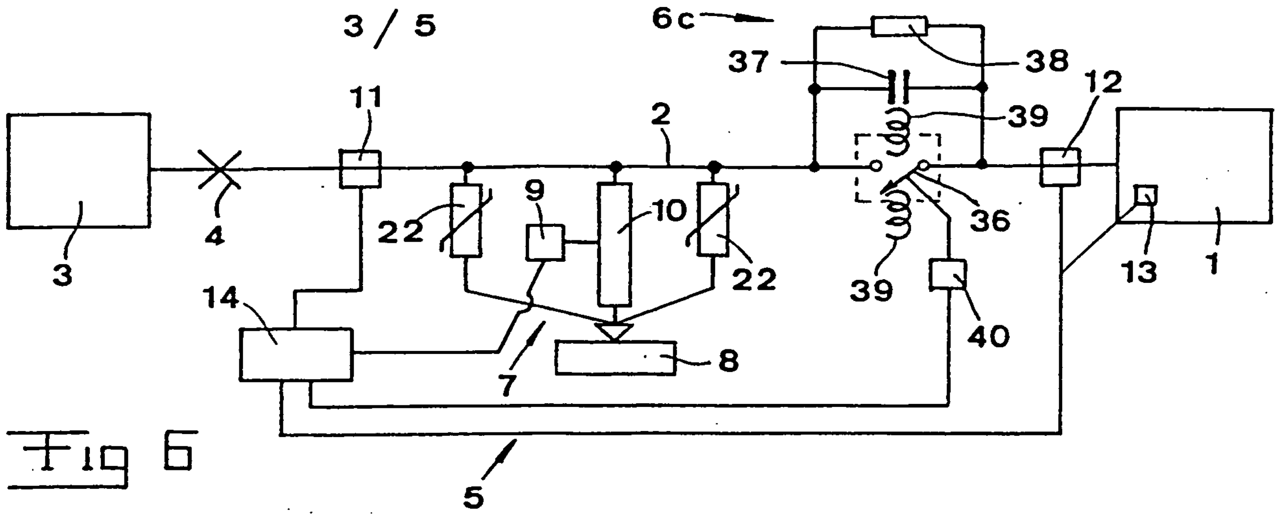

Fig 6

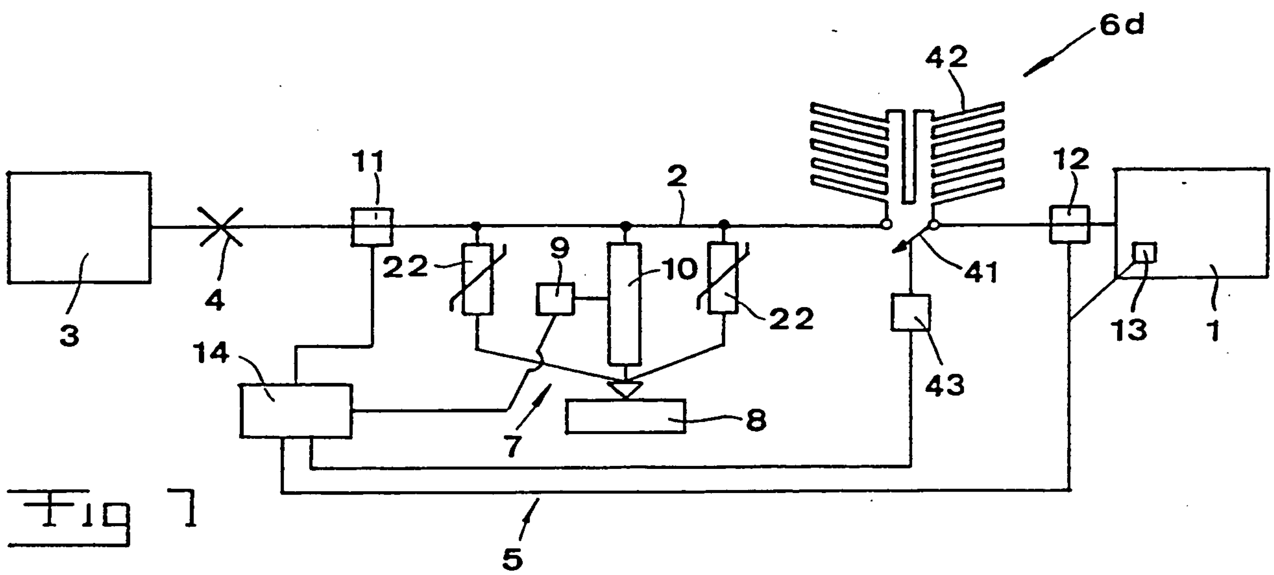

Fig 7

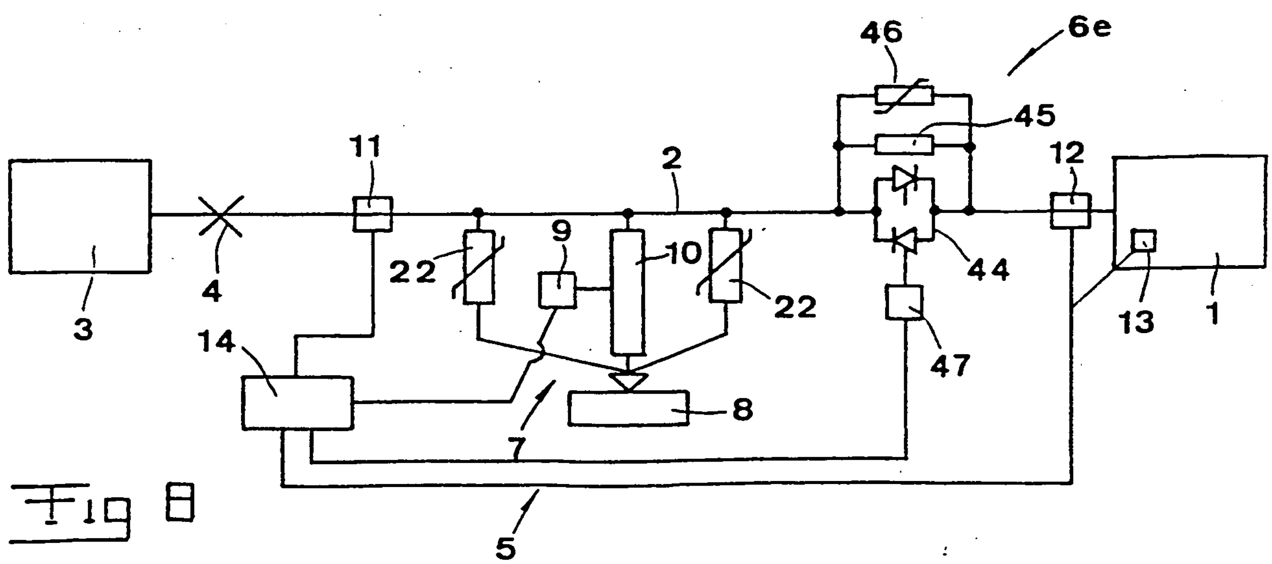

Fig 8

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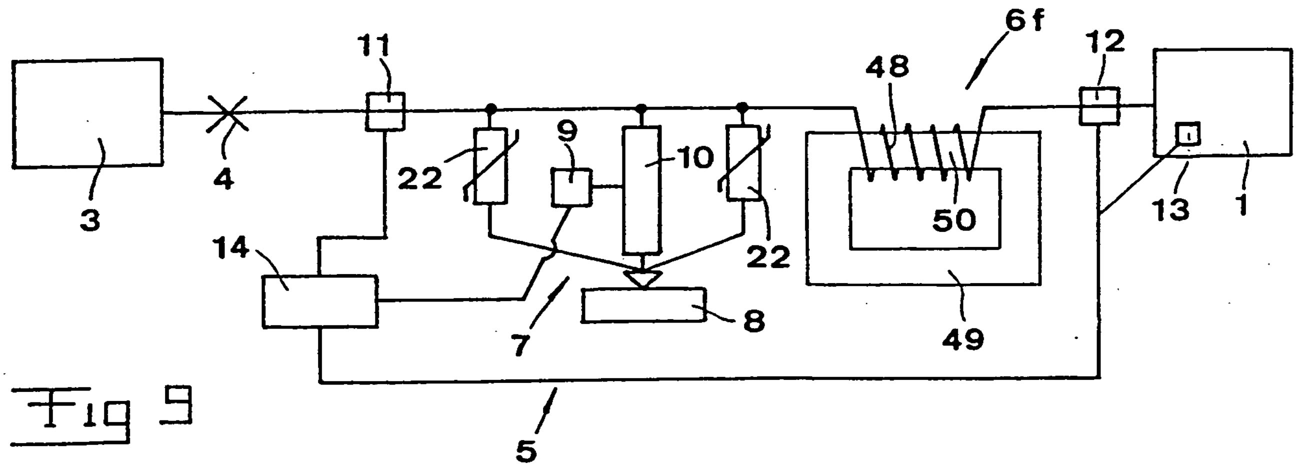


Fig 9

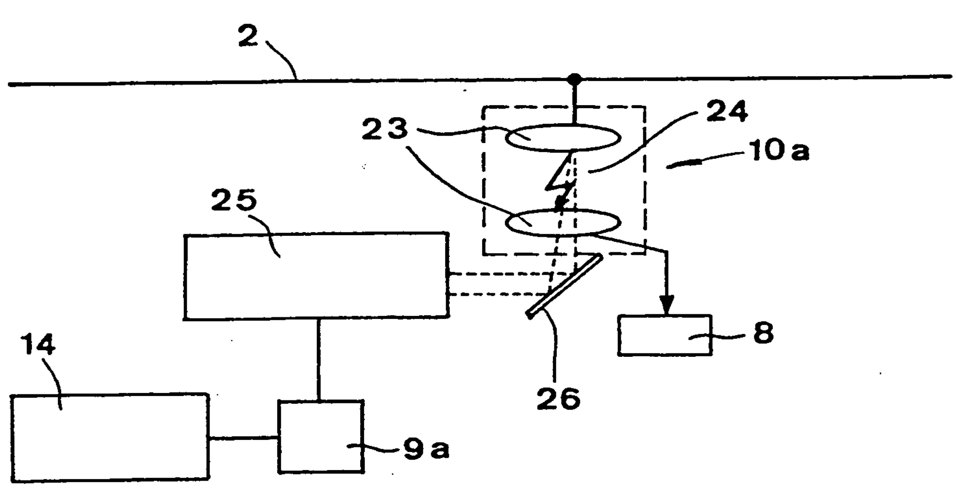
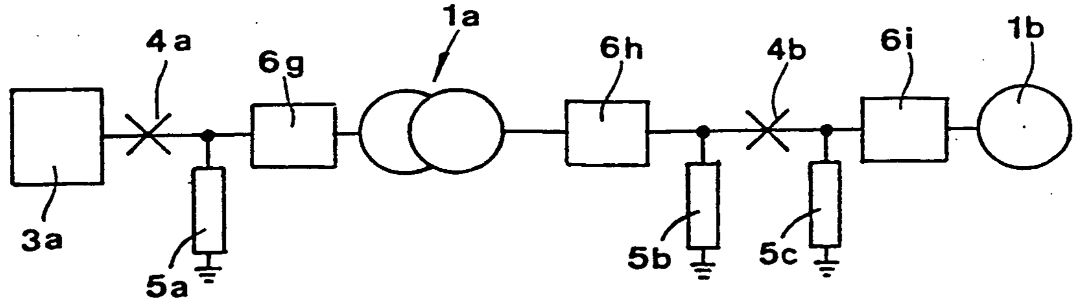


Fig 10

Fig 11



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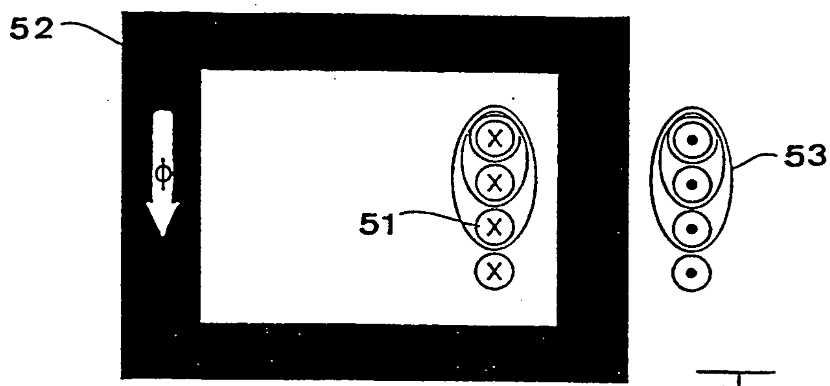
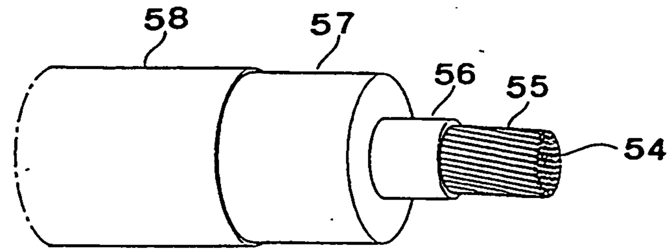


Fig 12

Fig 13



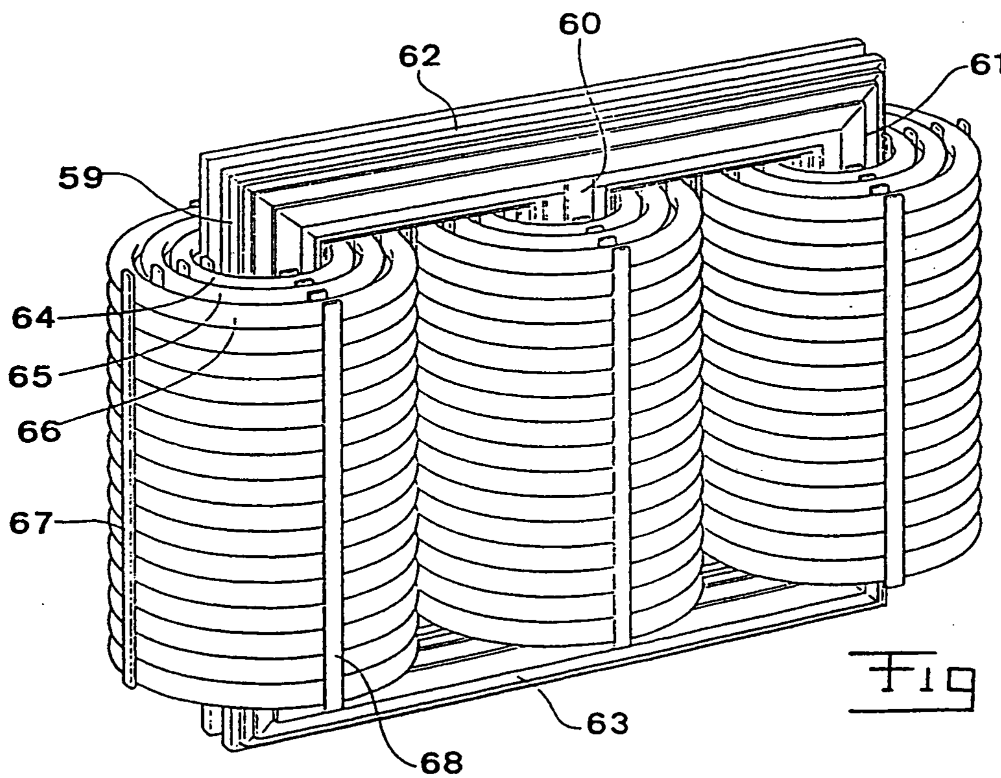


Fig 14

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00883

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02H 9/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02H, H01H, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4184186 A1 (P. BARKAN), 15 January 1980 (15.01.80), column 1, line 60 - line 62; column 2, line 16 - line 29; column 2, line 44 - line 51, figures 1,2, column 4-6, column 7, line 55 - line 61	1-5,9,21,22, 24,26-31, 40-47
Y		6-8,10-20, 23,25,32-39
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A	EP 0280759 A1 (WESTFÄLISCHE BERGGEWERKSCHAFTSKASSE), 7 Sept 1988 (07.09.88), column 4, line 30 - line 58, figure 1, abstract	5
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 December 1997	11 -12- 1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Karin Säfsten Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00883

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 3418530 A1 (W.H. CHEEVER), 24 December 1968 (24.12.68), column 1, line 45 - line 72; column 2, line 1 - line 15, figures 1,2 --	6,7
Y	US 5153460 A1 (L.J. BOVINO ET AL.), 6 October 1992 (06.10.92), column 1, line 12 - line 14, figures 1, 2, abstract --	8
Y	US 4523249 A1 (S. ARIMOTO), 11 June 1985 (11.06.85), column 1, line 27 - line 38; column 3, line 10 - line 40, figures 1-6 --	10-16
Y	US 4164772 A1 (N.G. HINGORANI), 14 August 1979 (14.08.79), column 1, line 5 - line 14; column 2, line 10 - line 68; column 3, line 1 - line 5, figures 1-7 --	17,19
Y	US 5140290 A1 (H. DERSCH), 18 August 1992 (18.08.92), column 2, line 30 - line 43, figures 1, 2, abstract --	20
A	US 4924342 A1 (R.H. LEE), 8 May 1990 (08.05.90), figures 1,2, abstract --	1,44
A	US 5136459 A1 (P. FARAROOY), 4 August 1992 (04.08.92), column 1, line 50 - line 68, figure 1 --	29

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00883

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5036165 A1 (R.K. ELTON ET AL.), 30 July 1991 (30.07.91), column 1, line 16 - line 60; column 2, line 26 - line 57, figure 1, abstract	32-39
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INTERNATIONAL SEARCH REPORT
Information on patent family members

01/10/97

International application No.
PCT/SE 97/00883

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